ON CONNECTING PANELS OF FREEFORM BUILDING ENVELOPES

A parametrical controlled connector system for non-standard CLT-structures using processed standard elements

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Abstract. As smooth geometric shapes are very tricky to manufacture with an overall great expense this paper presents a parametrical approach how to control the joint geometry within a framework of flat panels which approximate a freeform surface using discretization. Since timber has an excellent reputation as a sustainable and regenerative material plus the fact that timber can be perfectly processed with a large variety of tools including CNC milling machines we are using cross laminated timber boards (CLT) with large and heavy members. Hence that means dealing with high forces which require geometrically exact and often complex joints, which we want to push to a high degree of automation in the design process. We establish rules and constraints between all neighboring CLT-panels. That way we control a new connector system specially designed for non-standard CLT-joints. This paper documents the status of one aspect of an ongoing research project and will also give a preview to upcoming tasks including the production of a prototype structure.

1. Introduction

Generating smooth surfaces by discretization into flat panels has the advantage that we can use flat standard building elements [POTTMANN et al, 2007]. In our case, we are cutting a standard sized industrial building material like CLT into various shapes (see Fig. 1 left).

Figure 1. left: Standard Cross Laminated Timber (CLT) panels (image: www.finh-finnholz.com), right: Irregular structure with flat panels of CLT

This will keep the construction costs down independent of the choice of material. The new framework we define is based on parametric modeling of ornamentations and its aesthetics, which we consider as a unique input to the subject matter. Hence we translate flat ornaments and patterns into complex spatial structures and surfaces and more importantly into buildable architecture using plane standard building materials. Our framework is based on a set of rules which is able to produce a variety of different panels visually rich and complex [STAVRIC, 2010]. Parametric models will be designed as irregular three dimensional polygonal ornamental structures [SCHIMEK et al, 2008]. Such a parametric model can be assigned to a self-supporting structure like spatial separators, ornamental walls, façade elements, shading and acoustic panels. Figure 1 shows an example of such a structure which could be used as a climbing wall (see Fig. 1 right).
In this paper we propose an approach how to deal with the joints of the single elements based on structural analysis of the timber engineers. Finally the results of these calculations should be put into parameters which directly influence the geometry and orientation of the jointing system. We will

describe how we handle the design process both digitally and physically with a focus on construction and production.
Hani Bury from IBOIS institute of EPF-Lausanne worked on a related idea using thinner panels of CLT (21 mm) for a smaller structure combining the single panels with origami technique to a structure with a regular pattern whereas we are dealing with a multi-story structure with much heavier elements and forces [BURI, 2006]. Like Buri we will also carry out physical load tests on full-scale mock-ups.

2. The joint system within the parametrical framework

For parametric support we use a parametric modeller to maintain flexibility of the connector system. This secures the possibility of adapting the system to all possible structural specifications and variations of the initial shape. We use Grasshopper and Rhino-Script to integrate the data derived from the structural engineers analysis into the geometrical model. With reverse engineering we want to optimize our panels following both structural and aesthetical guidelines. For this purpose we "wed" all neighbouring edges of each panel in the digital model to involve all the parameters defined by the joint geometry and load analysis. In other words all information, like how the panels interact with each other, how many connectors are used and their orientation is stored in the panels as meta data. As a possible joint system we introduce a new system which we call "sewed" joints because of the similarity of the stitch pattern to the stiches of a seam.

Currently we perform intensive FEM load analysis which covers self-weight, wind and snow loads which is calculated over all designated panels of the entire structure where we apply the connector system to. In this context of construction we refer to *Constructive Parametric Design* as an automated support method in the design process [SCHIMEK et al, 2008].
Another aspect which will be taken into account is the management of tolerances of the joints. According to Whitehead who has used tolerance management in the construction of London's City Hall we will also examine how tolerances will influence our construction system [WHITEHEAD, 2003].

3. Construction of the "sewed" joints

3.1 REQUIREMENTS FOR THE JOINTS

- The joints of the single panels have to transfer both, positive and negative axial forces, lateral forces and bending moments because these space structures made of clue laminated timber panels (CLT) carry all loads without any additional structure.

- Simultaneously the joints must be as efficient as possible because of aesthetic and economic reasons. That means, that the load-bearing capacity of the joints should not be much lower than the panels it one. Areas with low stresses get a smaller number of connectors.
- Due to the deformations of the hole spatial structure, the joints have to be rigid.

3.2 CONCEPT

At the moment no such joints for space structures made of CLT-panels exist [SCHICKHOFER et al, 2010], therefore a new joint, a so called "sewed" joint is suggested (see Fig. 3).

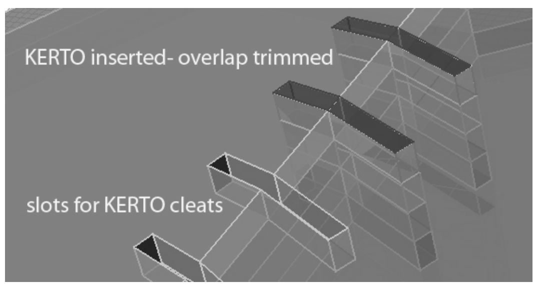

Figure 3. The “sewed” joints showing the KERTO cleats cut through all layers of the CLT element and slots before insertion

With a CNC-machine slots are cut into the panels to glue parallel laminated veneer (cleats made of KERTO-S which is an engineered material with high mechanical load capacity). According to the stresses, the interval (a) of the cleats can be modified (see Fig. 4).

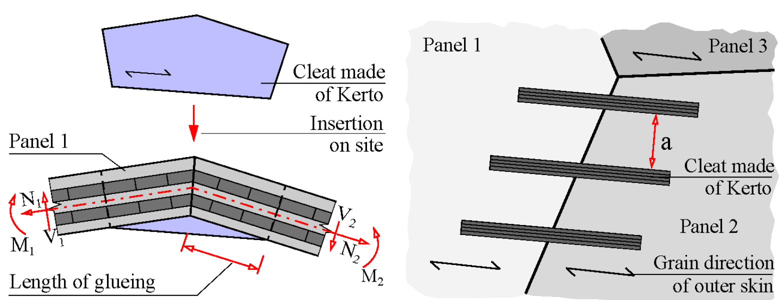

Figure 4. The “sewed” joints, left: cross section showing axial forces N_1 resp. N_2, lateral forces V_1 resp. V_2 and bending moments M_1 resp. M_2, right: top view.

3.3 FURTHER FACTORS INFLUENCING THE CONSTRUCTION OF THE JOINTS

- Caused by the anisotropic material behavior of wood, deviations between the grain direction of the outer layer of the CLT-panels and the cleats have to be avoided as far as possible. Tensile stresses perpendicular to the grain in the panels should be as little as possible.
- Tolerances due to manufacturing
- Requirements of the assembly and
- of the transport (size of the elements)

4. The parameters of the digital model

So far we parameterized the following specifications (see Fig. 5):

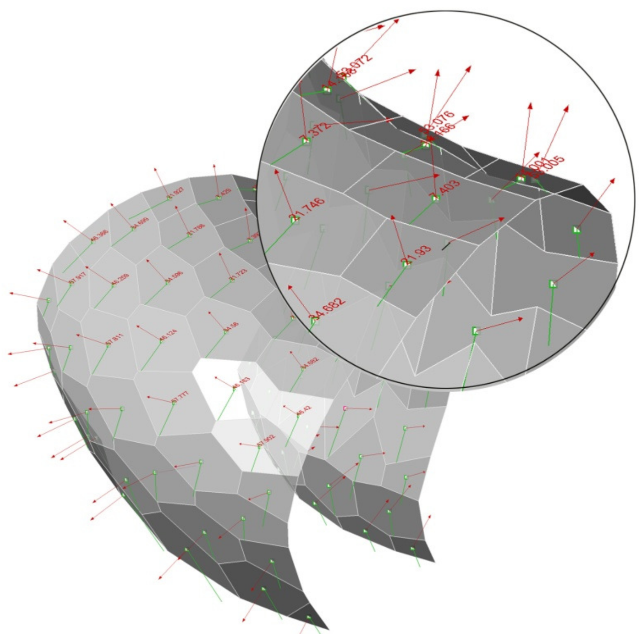

Figure 5. Digital model, shaded surface model showing crucial angles for snow load (green), surface normals at the centroids (red).

- Grain direction of outer CLT-layer - as pointed out before the grain and the cleat direction must not deviate respectively should be kept as small as possible. In the digital model all panel edges need to be identified to appoint a material's grain direction which fits all panels of the whole structure. An algorithm optimizes the direction for each panel to meet the requirement of the maximum deviation mentioned before. This way we control the orientation of the Kerto cleats.

- Panel inclination - only values < 60° will be taken into account for the calculation of snow loads since snow does not remain on roof pitches > 60°.
- Load cases as self-weight, static and dynamic traffic loads and wind loads are currently calculated independently from the digital 3D-model but will find its equivalent in the model later on. All loads cases will contribute to define the
- Interval and the dimensions of the KERTO-cleats
- Nesting of the panels - before the components can be produced from standard CLT-sheets which usually have a standard size of 295 x 1600 cm we have to use the data of the grain direction identification to unroll and outlay on the raw sheets. For that purpose the panels have to be rotated according to the grain direction obtained from the digital model. Thus we achieve to use the CLT sheets in a material efficient way with a minimum of cut-off.

We are currently working on a proper identification of the panels for file transfer reasons. It is crucial to clearly indicate the panels in space, saying which edges belong to which faces and which space coordinates define one component to prevent the individual components from shuffling in space when being exchanged between different software tools (CAD >> FEM).

5. Complexity and sustainability - future prospects

The milling will be performed on a 6-axis industrial robot with an additional linear unit which we just recently got granted at our faculty.

Furthermore we will implement this parametrical framework into a software plug-in which enables architects to work with planar CLT-panels on dual-curved surfaces without going through complicated construction processes which has dogged architects ever since when it comes to deal with the construction of dual-curved surfaces. This improves both design freedom and flexibility while shortening construction design time without reducing complexity [SCHODEK et al, 2005].

Many of today's construction materials have an ecologically disadvantageous impact on the environment. On the other side there is

wood as a versatile, cost-competitive material which is easy to work with and which has an excellent eco-balance because it's renewable and can be recycled at the end of its life. The capability of trees taking carbon out of the atmosphere and storing it for many years helps to reduce global warming [LUTHE, 2008].
Our aim is to use this well appointed material in a responsible way by taking advantage of digital technology which enables us to gain sustainability in several realms. The economical use of resources by optimizing the blanking and a timesaving design process by automating the design using parametrical support in the design process optimize the design both in terms of the aesthetics and functionality while reducing planning time.
Production benefits in a way that errors can be prevented because all project participants are using the same data model, changes are communicated without any data loss or redundancies - paper drawings will most likely disappear [KOLAREVIC, 2003]
Thus we also see a strong potential for the prefab house industry where our approach will lead to a higher degree of design freedom what can be economically afforded because of reduced costs in design and production.

Acknowledgements

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